Micropaleontology of the JAPEX/JNOC/GSC Mallik 2L-38 gas hydrate research well

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Abstract: Core and cuttings samples from the JAPEX/JNOC/GSC Mallik 2L-38 gas hydrate research well in the Mackenzie Delta have yielded sparse terrestrial microfossils and abundant reworked Cretaceous foraminifers (silicified) and plant microfossils. No definitely in situ marine microfossils were recovered in the borehole (total depth 1150 m; gas hydrate at 896–1110 m). Cores from 110–118 m and 173–175 m contained terrestrial microfossils including fungi, seeds, insect fragments, and abundant macerated plant fragments typical of the Pliocene–Pleistocene Iperk Sequence in the Mackenzie–Beaufort Basin. Core from 886–951 m and cuttings samples from 670–870 and 960–1140 m yielded reworked algal cysts, seed casings, and megaspores. In addition, cuttings contained reworked Cretaceous agglutinated foraminifers. Core and cuttings samples were also characterized by quartz, chert, brownish-black lignite, coaly fragments, and rare amber. The lithology of the section below 670 m is characteristic of the Oligocene Kugmallit Sequence in the Mackenzie–Beaufort Basin.

Résumé : Des échantillons de carottes et de déblais prélevés dans le puits de recherche sur les hydrates de gaz JAPEX/JNOC/GSC Mallik 2L-38 foré dans le delta du Mackenzie renferment des microfossiles terrestres épars et d'abondants foraminifères (silicifiés) et microfossiles végétaux remaniés du Crétacé. On n'y a prélevé aucun microfossile marin vraiment en place (profondeur totale du sondage : 1 150 m; présence d'hydrates de gaz entre 896 et 1 110 m). Les carottes extraites entre 110 et 118 m et entre 173 et 175 m renferment des microfossiles terrestres, notamment des eumycètes, des graines, des fragments d'insectes et d'abondants fragments de végétaux macérés, typiques de la Séquence d'Iperk du Pliocène–Pléistocène dans le bassin de Mackenzie–Beaufort. Les carottes extraites entre 886 et 951 m et les échantillons de déblais prélevés entre 670 et 870 m et entre 960 et 1 140 m contiennent des kystes algaux, des enveloppes de graines et des macrospores remaniés. Les déblais de forage contenaient en outre des foraminifères agglutinés remaniés du Crétacé. Les échantillons de carottes et de déblais sont caractérisés par la présence de quartz, de chert, de lignite noir brunâtre, de fragments charbonneux et, rarement, d'ambre. La lithologie de la section au-delà de 670 m est typique de la Séquence de Kugmallit de l'Oligocène dans le bassin de Mackenzie–Beaufort.

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INTRODUCTION

The Mackenzie Delta and neighbouring Beaufort Sea have been extensively drilled during the last 30 years, with 247 exploration wells sunk (Dixon, 1996). The vast majority of these wells were drilled for conventional deposits of oil and gas. Drilling in the Mackenzie Delta revealed a thick section of permafrost and the occurrence of thick deposits of gas hydrate (Bily and Dick, 1974). The Mallik L-38 well, for example, penetrated gas-hydrate-bearing strata at depths of 819 to 1111 m, hence the Mallik 2L-38 gas hydrate research-well site (69°27′38.57″N; 134°34′24.6″W) was chosen for a jointly funded coring program to fully characterize an arctic gas hydrate occurrence. The drilling and scientific program was carried out jointly by Japan Petroleum Exploration Company (JAPEX), the Japanese National Oil Corporation (JNOC), the United States Geological Survey (USGS), and the Geological Survey of Canada (GSC).

Compilations of biostratigraphic data from previous exploration wells have focused mainly on foraminifers (McNeil, 1996a, b, c, 1997) and palynomorphs (Norris, 1986, 1997; McIntyre, 1996a, b; White, 1989), with cuttings samples being the main source of micropaleontological data. It was anticipated that core from the JAPEX/JNOC/GSC Mallik 2L-38 gas hydrate research well would provide an opportunity to study mid- to late-Cenozoic history of the Mackenzie Delta area in more detail than was previously possible. A number of factors, however, combined to interfere with the anticipated recovery and results. To begin with, the upper 687 m of borehole drilling was seriously delayed by technical problems and poor recovery. Nonetheless, eight cores were cut between 105 and 176 m, and cores from 110 to 118 m and 174 to 176 m were sampled for microfossils (Fig. 1) (all depths were measured from kelly bushing [8.31 m above sea level]). Attempted coring between 790 and 825 m provided no core recovery, apparently as a result of unconsolidated gravel in the bottom of the hole. Drilling was more successful below 825 m. Cores 12 to 24 were cut between 886 and 951 m and samples were collected and processed for microfossils (Fig. 1). Cuttings samples were collected from below the cemented casing, i.e. from 670 m to total well depth (TD) at 1150 m, and these were examined for microfossils at approximately 20 m intervals above and below the main cored section. Unfortunately, there were no definite marine units identified in any of the core and cuttings samples examined, and the recovery of nonmarine microfossils was, in general, very poor. The most abundant microfossils recovered proved to be silicified agglutinated foraminifers that were recycled from Cretaceous rocks.

Concurrent with the micropaleontological study, palynological studies on the Mallik 2L-38 well were conducted by Kurita and Uchida (1999) and White (1999). Kurita and Uchida recognized Cretaceous, Paleocene, and Eocene dinoflagellates reworked in fluvial sediments assigned to the Miocene–Oligocene Mackenzie Bay and Kugmallit sequences. White (1999), on the other hand, considered that some of the pollen and spores and some of the dinoflagellates in the Mallik 2L-38 (between 670 and 1150 m) were indigenous and diagnostic of Miocene and Eocene sedimentation (Richards and Taglu sequences, below 930 m). The interpretation of the Richards and Taglu sequences within the lower 220 m of the Mallik 2L-38 well, however, is highly unlikely. This is based on personal and published observations on the lithology, micropaleontology, and distribution of Eocene to Miocene sequences in the Mackenzie–Beaufort Basin and on the reported occurrence of the Richards Sequence (Dixon, 1990; McNeil and Birchard, 1989) in the adjacent Mallik L-38 well from 1934 to 2532 m (target depth TD) — i.e. much lower than the total depth drilled for the Mallik 2L-38 well. It is more likely that the majority of the pollen and spores, and all of the dinoflagellates and foraminifers in the Mallik 2L-38 well are reworked.

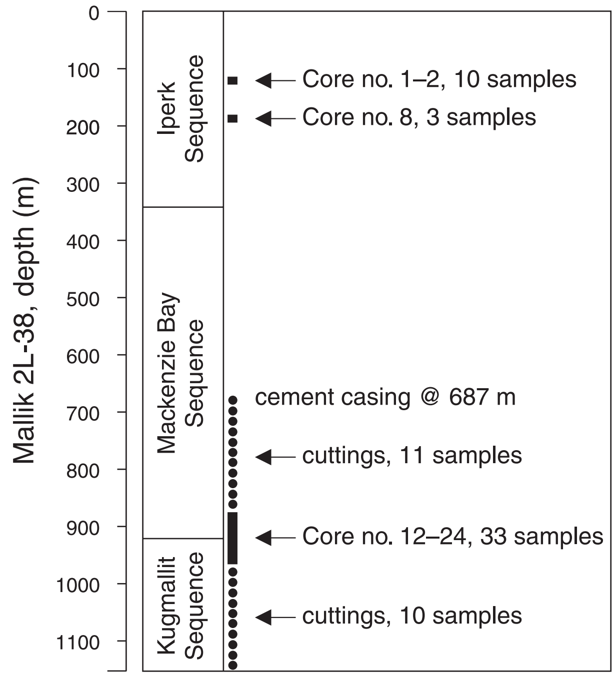

Figure 1. *Stratigraphic position of samples examined for microfossils in the Mallik 2L-38 well. Sequence stratigraphy from Jenner et al. (1999). See Figure 2 for detailed listing of sample intervals.*

METHODS

A total of 46 core samples and 21 cuttings samples were collected from the Mallik 2L-38 borehole (Fig. 1, 2). All of the samples were processed for a variety of plant and invertebrate microfossils including fungi, algal cysts, seeds, foraminifers, radiolarians, ostracods, and bivalves (Fig. 3). Macerated plant debris and lignite/coaly fragments were recovered in abundance in most of the samples.

The micropaleontological processing followed techniques similar to those outlined by Then and Dougherty (1983). Core samples ranged from 5 to 76 g and were disintegrated mechanically and chemically on an oscillating hot plate (70°C) in Quaternary "O"™ (a specialized detergent)

	Sample interval (m)	Sample weight: Initial weight (g)	Sample weight: Washed residue weight (g)	Washed residue lithology: grain size	quartz	lithic grains	chert	pyrite	plant fragments	woody lignitic debris	coal	amber	calcareous cement	ironstone?
Core no. 1–2	110.12–110.14	11	1	f	xxxxx	xxxxx			xxxxx					
	111.57–111.59	14	2	f	xxxxx	xxxxx			xxxxx					
	112.47–112.49	31	4	f	xxxxx				xxxxx					
	113.28–113.30	29	3	f	xxxxx	xx			xx					
	113.97–113.99	9	1	f	xxxxx	xx			x					
	114.92–114.94	18	1	f	xxxxx	xxx			xxxxx					
	115.80–115.82	16	7	f	xxxxx	xxxxx			xxxxx					
	116.87–116.89	21	3	f	xxxxx	xxx			xxxxx					
	118.07–118.09	15	1	f	xxxxx	xxxxx			xxxxx					
	118.32–118.34	11	2	f	xxxxx	xxxxx						x		
Core no. 8	173.57–173.59	10	1	f	xxxxx	xxxxx								
	174.84–174.85	6	2	f	xxxxx	xxxxx			xxxxx					
	175.43–175.45	5	1	f	xxxxx	xxxxx								
Cuttings	670	100	23									x		
	690	100	2	f–c	xxxxx		xxxxx							
	710	85	36											
	730	100	17	f–c	xxxxx		xxxxx			xxx				
	750	100	17											
	770	50	8	f–c						xxxxx	xxx	x		
	785	50	8											
	810	50	18	f–c	xxxxx	x	xxxxx	x		xxx	x			
	830	50	10											
	850	50	15	f–c	xxxxx	x	xxxxx	x		xxx	x			
	870	50	5											
Core no. 12–24	886.39–886.40	42	1	vf	xxxxx			xxx		xxx	x			
	890.71–890.72	59	1	vf	xxxxx		x	xxx		xxx	x			
	891.07–891.09	28	1	vf	xxxxx		x			xxx	x			
	892.50–892.52	112	6	vf–f	xxxxx		x	xxxxx		xxxxx		x		
	893.17–893.19	23	1	vf	xxxxx		x	xxx		xxxxx		xxx		
	896.70–896.72	47	1	vf–c	xxxxx		xxx	xxx		xxxxx	x			
	897.35–897.37	48	1	vf–c	xxxxx		xxxxx	xxxxx		xxxxx	x	x		
	900.43–900.45	49	13	f–c	xxxxx		xxxxx							
	900.62–900.64	25	1	f–c	xxxxx		xxxxx	xxxxx		xxx				
	903.00–903.02	15	1	vf	xxxxx			xxx		xxxxx	x			
	903.34–903.36	15	10	f	xxxxx		xxxxx			xxxxx				
	903.81–903.83	10	3	f	xxxxx		xxxxx	xxxxx		xxxxx				
	905.73–905.75	31	1	f	xxxxx		xxx	xxx		xxx				
	906.57–906.59	11	1	vf	xxxxx		x	xxx						
	911.99–912.01	13	4	f	xxxxx		xxxxx	x		xxxxx	xxx			
	920.30–920.32	25	2	f	xxxxx		xxxxx							
	921.38–921.40	10	2	f	xxxxx		xxxxx							
	925.51–925.52	20	14	f	xxxxx		xxxxx						x	
	925.70–925.71	20	13	f	xxxxx		xxxxx						x	
	928.00–928.02	11	1	f	xxxxx		xxxxx	xxxxx		x	x			
	936.32–936.33	23	1	f	xxxxx		xxxxx			xxxxx	xxxxx			
	936.75–936.77	40	1	f	xxxxx		xxxxx			xxxxx	xxxxx			
	937.35–937.37	33	1	vf	xxxxx		xxxxx							
	939.05–939.07	40	1					xxx		xxxxx				
	943.72–943.74	18	5							xxxxx	xxxxx			
	944.31–944.33	18	1	vf	xxxxx		xxxxx			x				
	945.20–945.22	41	1	f	xxxxx			xxxxx		x				
	946.20–946.22	62	1	f	xxxxx		xxxxx	xxx		x	x			
	947.60–947.62A	76	5	s	x		x							xxxxx
	947.60–947.62B	27	1	vf	xxxxx		xxxxx			x				
	949.20–949.22	20	1	vf	xxxxx		xxxxx			x				
	950.10–950.12	64	1	f	xxxxx		xxxxx				xxx			
	951.28–951.30	21	1	vf	xxxxx		xxxxx	xxx						
Cuttings	960	50	9	f–c	xxxxx	x	xxxxx	x		xxxxx	x			
	980	50	8											
	1000	50	7	f–c	xxxxx	x	xxxxx	x		xxx	x			
	1020	50	5											
	1040	50	9	f–c	xxxxx	x	xxxxx	x		xxx	x			
	1060	50	11											
	1080	50	8	f–c	xxxxx	x	xxxxx	x		xxxxx	x			
	1100	50	5											
	1120	50	6	f–c	xxxxx	xxx	xxxxx	xxx		xxxxx	xxx			
	1140	50	9											

Explanation:

Grain Size
vf = very fine
f = fine
f–c = fine to coarse

Abundance
X = rare, minor
XXX = common
XXXXX = abundant

Figure 2. *Generalized lithology of core and cuttings samples analyzed for microfossil content in the Mallik 2L-38 well. Lithology is based on cursory examination of disaggregated washed sediment greater than 75 microns.*

		Fungi, algal cysts, megaspores, seeds													Reworked foraminiferas																	Miscellaneous						
	Sample Interval (m)	*Carex* sp.	*Cennococcum geophilum*	*Leiosphaeridia* sp.	*Lancettopsis* sp.	*Ranunculus*? sp.	seed husk, spongy	*Costatheca* sp.	seed?	*Dictyothylakos* sp.	*Arcellites nudus*?	*Spermatites* sp.	*Tasmanites* sp.	*Typha* sp.	*Bathysiphon brosgei*?	*Haplophragmoides* spp.	*Ammobaculites tyrrelli*?	*Haplophragmoides multiplum*?	*Miliammina manitobensis*	*Ammobaculites* sp.	*Haplophragmoides bilobatus*	*Hippocrepina*? sp.	*Saccammina lathrami*	*Trochammina tukensis*?	*Verneuilinoides*? sp.	*Ammobaculites* sp.	*Glomospirella arctica*	*Recurvoides*? spp.	*Bathysiphon* sp.	*Glomospira* sp.	*Haplophragmoides carinatus*?	*spicule*	*bryozoan* (statoblast)	insect fragments	*ostracod* (smooth walled)	beetle *carapace*	bivalve shell fragment	*Cenosphaera* sp.
Core no. 1–2	110.12-110.14																																					
	111.57-111.59														1	1																1						
	112.47-112.49	1	4	2	1												1	1	1														1	2	2			
	113.28-113.30																																					
	113.97-113.99		1	1																																		
	114.92-114.94																																					
	115.80-115.82		1			1										1																			1			
	116.87-116.89		4																																			
	118.07-118.09		2				1																													3		
	118.32-118.34							1																														
Core no. 8	173.57-173.59																																					
	174.84-174.85								1							8				4	1	2	1	2	2									1				
	175.43-175.45															4										2												
Cuttings	670																1						1		1							1					1	
	690		2																																			
	710																																					
	730																																					
	750																																					
	770																																					1
	785															2									1		1	1				1						2
	810																						1															
	830																											1	1			1						1
	850									1																												2
	870															2																2						
Core no. 12–24	886.39-886.40																																					
	890.71-890.72																																					
	891.07-891.09		2																																			
	892.50-892.52																															1						
	893.17-893.19									1																												
	896.70-896.72																																					
	897.35-897.37			1							1	2	1	2																								
	900.43-900.45																																					
	900.62-900.64																																					
	903.00-903.02																																					
	903.34-903.36																																					
	903.81-903.83																																					
	905.73-905.75																																					
	906.57-906.59																																					
	911.99-912.01																																					
	920.30-920.32																																					
	921.38-921.40																																					
	925.51-925.52																																					
	925.70-925.71																																					
	928.00-928.02																																					
	936.32-936.33																																					
	936.75-936.77																																					
	937.35-937.37																																					
	939.05-939.07																																					
	943.72-943.74																																					
	944.31-944.33																																					
	945.20-945.22		1									2																										
	946.20-946.22																																					
	947.60-947.62A																																					
	947.60-947.62B																																					
	949.20-949.22																																					
	950.10-950.12																																					
	951.28-951.30																																					
Cuttings	960																																					
	980																						2															
	1000																																					
	1020																																					
	1040															1							2							1								5
	1060				1																																	
	1080																										1											4
	1100																														1							
	1120															2												2										1
	1140															2																						

Figure 3. *Microfossils recovered from core and cuttings samples in the Mallik 2L-38 well, Mackenzie Delta. See Figure 2 for additional information on sample size and lithology. The numbers indicate the number of specimens recovered.*

followed by hydrogen peroxide (35%). The disaggregated sediment was washed on a sieve and the fine fraction (≤75 micron) was discarded. The ≥75 micron sized fraction was scanned under a binocular microscope for microfossils. Breakdown of the sediment was generally excellent, except for a dolomite-cemented sandstone at 925 m.

Cuttings samples were processed only from the section below casing, starting at 670 m. Samples of 50 to 100 g were analyzed at about 20 m intervals down to the total depth of the well. Like the core samples, the cuttings samples were oscillated in Quaternary "O"™ on a hot plate (70°C) followed by washing on a 75 micron screen. Cuttings samples were not analyzed over the cored interval from 886 to 952 m. Comparison of adjacent core and cuttings samples indicates that recovery was different from the two sample sets, with the cuttings containing more microfossils than the core. The core samples were probably biased by the collection of finer grained samples, and the cuttings samples represent a more continuous sampling of fine- to coarse-grained sediment. Apparently, the resistant silicified Cretaceous foraminifers and radiolarians were concentrated and transported in the coarser grained sediments.

All core and cuttings samples, washed residue, and microfossil slides used in this study are curated at the GSC, Calgary. The original core and cuttings samples are stored at GSC, Ottawa.

MICROPALEONTOLOGY

Micropaleontological samples were analyzed from three main sections of core: 1) cores no. 1–2 (105–123 m), 2) core no. 8 (167–176 m), and 3) core no.12–24 (886–952 m). Cuttings samples were analyzed from below casing from 670 to 870 m and 960 to 1140 m. Micropaleontological results (Fig. 3) indicate that the section probably is entirely nonmarine, as no definite in situ marine microfossils were recovered. In general, the recovery was very poor, with the majority of microfossils being recycled marine microfossils consisting of foraminifers with lesser numbers of radiolarians.

Cores no. 1–2 (105–123 m)

Samples from core runs 1 and 2 yielded a fine-grained residue consisting of quartz grains with a conspicuous number of lithic grains. Macerated plant debris, showing little sign of thermal alteration, was abundant in most samples. No microfossils were found in abundance, but rare occurrences of 'in situ' seeds, including *Carex* sp. and *Ranunculus*? sp., and sclerotium of the fungus *Cennococcum geophilum* Fries were recovered. Other probable 'in situ' microfossils include bryozoan statoblasts (*Cristatella mecedo* Cuvier), beetle carapaces, and unidentified insect fragments. Recycled microfossils included rare specimens of the algal cysts *Lancettopsis* and *Leiosphaeridia*, and seed casings assigned to *Costatheca* sp. Numerous specimens of recycled agglutinated foraminifers were recovered in this core interval. Specimens typical of Albian rocks consisted of *Bathysiphon brosgei* Tappan, *Ammobaculites tyrrelli* Nauss, *Haplophragmoides multiplum*? Stelck and Wall, and *Miliammina manitobensis* Wickenden.

The occurrence of *Carex* sp. suggests wetlands; *Ranunculus* spp. are often found in moist or wet habitats, and *Cenococcum geophilum* is a common fungus growing mainly on woody plants in a variety of ecological habitats including peat deposits in temperate to arctic areas (Bennike, 1990). Although the recovery was very poor, the assemblage of 'in situ' and recycled microfossils from this core is typical of Pliocene–Pleistocene sediments of the Iperk Sequence in the Mackenzie–Beaufort Basin.

Core no. 8 (167–176 m)

Three samples examined from core no. 8 yielded mostly an assemblage of recycled foraminifers, derived at least partially from Upper Cretaceous rocks. The occurrence of *Haplophragmoides bilobatus* McNeil and *Trochammina tukensis*? McNeil suggested that Campanian rocks were a major source for sediment at this time of deposition. An extremely meagre 'in situ' recovery consisting of an unidentified seed and some insect fragments were also recovered from core no. 8. The sediment in the washed residue for core no. 8 resembled closely that of the stratigraphically higher cores no. 1–2, and consisted of fine grains of quartz and lithic fragments, but with less-abundant macerated plant debris. The age and environment of core no. 8 could not be determined with assurance, but the dominance of recycled microfossils, impoverished plant microfossils, and sporadic abundance of macerated plant fragments is consistent with a generalized Pliocene–Pleistocene age and the Iperk Sequence.

Cores no. 12–24 (886–952 m)

A major change in lithology was indicated in the washed residues derived from the nearly continuous cored section from 886 to 952 m, which extends into the main gas-hydrate-bearing section (896–1110 m). The sediment observed in these core samples consisted of fine grains of quartz and chert with pyrite commonly encrusting grains and cementing small (≤2 mm) clumps of sediment. An abundance of dark brown to black, woody, lignitic/coaly material and rare amber was also characteristic of most samples. Unfortunately, cores no.12–24 were remarkably poor in microfossil content. A few microscopic plant specimens were recovered, including sclerotium of the fungus *Cennococcum geophilum*, the algal cyst *Leiosphaeridia*, seeds from cattails (*Typha* sp.), the megaspore *Arcellites nudus* (Cookson and Dettman), seed casings (*Spermatites*), and *Incertae sedis* (*Tasmanites* and *Dictyothylakos*).

No definitive conclusions regarding the age and stratigraphic position of this section could be drawn based on microfossils, but the abundance of chert, quartz, lignite/coal, and rare amber is similar to that normally found in proximal facies of the Oligocene Kugmallit Sequence (personal observations of cuttings from the Mallik L-38 and P-09 wells, D.H. McNeil).

Cuttings samples (670–870 and 960–1140 m)

In the absence of core, cuttings samples were examined from below the cement casing, starting at 670–870 m and from 960–1140 m with a sample interval of approximately 20 m. Lithologically, the washed residues from the cuttings samples were similar to samples from cores no. 12–24, but a conspicuous increase in the grain size was observed. A significant number of recycled microfossils were also recovered from the cuttings. Cuttings samples both above and below the core were dominated by quartz and chert, with most samples containing abundant lignitic/coaly debris, common pyrite, and rare amber. Lithic grains were also more common in the cuttings samples. The different recoveries between the core samples and adjacent cuttings samples can probably be explained by a selective bias in the core samples towards the finer grained lithologies. A marked presence of reworked foraminifers in the cuttings samples suggested that the reworked microfossils were concentrated in the coarser grained fraction of sediment. There were no in situ marine fossils recovered from the entire set of cuttings samples, with the possible exception of a single specimen of *Haplophragmoides carinatus*? Cushman and Renz (late Eocene to middle Miocene) at 1100 m. Without additional specimens and a more complete foraminiferal assemblage, no definitive conclusions can be drawn on this single occurrence. The provenance of the reworked foraminifers is not certain because most of the specimens could not be identified to species level. The occurrence of *Glomospira arctica* Chamney indicates an early Cretaceous age. Radiolarians of the genus *Cenosphaera* occurred fairly consistently in the cuttings samples. Their origin is uncertain, but they could be derived from Campanian rocks which are known to have radiolarian-rich units in the Arctic (Wall, 1983).

The cuttings samples appeared to be broadly similar in lithology to the cores no. 12–24, and they are tentatively considered to be of Oligocene age in a proximal facies (delta plain) of the Kugmallit Sequence.

DISCUSSION AND SUMMARY

The primary purpose of this micropaleontological investigation was to examine the core and cuttings samples from the Mallik 2L-38 gas hydrate research well for marine microfossils. Examination of 46 core samples and 21 cuttings samples failed to find any clear evidence of in situ marine microfossils, but occurrences of reworked, mostly Cretaceous, foraminifers were common, and some possible in situ terrestrial microfossils were recovered. Sampling in the upper part of the well was hampered by drilling problems, but cores no. 1–2 (110–118 m) and no. 8 (173–175 m) were sampled for microfossils. These samples yielded seeds such as *Carex* and *Scirpus* which are characteristic of Pliocene–Pleistocene arctic sediments. Relatively unaltered, macerated plant debris was also abundant in these samples. Reworked foraminifers, algal cysts, and megaspores were also common. The assemblage is virtually identical to that recovered from strata assigned previously to the Iperk Sequence in the neighbouring Mallik L-38 well and an undifferentiated Pliocene–Pleistocene age is likely for the strata in cores no. 1–2 and 8.

The next successful core recovery produced cores no. 12–24 (886–951 m) which yielded a very meagre recovery of reworked microfossils. Cuttings samples from below the cement casing, starting at 670 m and continuing to 1140 near the well TD (1150 m), were examined. The microfossil recovery was noticeably different between the core samples and the cuttings samples, and this was apparently the result of the core samples being specifically biased towards the finer grained facies as suggested by an increase in the grain size of the sediment in the washed residue. In comparison to the uphole samples from cores no.1–2 and 8, the lithological composition of the washed residue was markedly different in the samples below 670 m. Quartz, chert, dark brown lignitic, coaly grains, and rare amber dominated the residues below 670 m, whereas quartz, lithic fragments, and relatively fresh plant fragments dominated the samples between 110 and 175 m. Virtually no in situ material was recovered from below 670 m. Reworked silicified agglutinated foraminifers were common in the cuttings but absent in the (finer grained) core samples. One occurrence tentatively referred to as *Haplophragmoides carinatus*? Cushman and Renz (late Eocene to middle Miocene) at 1100 m was possibly in situ. The meagre recovery and lithological character of the samples from 670 to 1150 m in the Mallik 2L-38 borehole was similar to the recovery from the Mallik L-38 well from approximately 1350 to 6800 ft, and from the Mallik P-59 well from 3400 to 5400 ft (unpub. data from collections at GSC Calgary). These strata have been assigned previously to the Kugmallit Sequence (Dixon et al., 1992) and a generalized Oligocene age is assigned based on regional correlations of the Kugmallit Sequence in the Beaufort–Mackenzie Basin (Dixon et al., 1992; McNeil, 1997).

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